MAGNETIC DESULFURIZATION OF SOME ILLINOIS BASIN COALS*

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INTRODUCTION

High extraction magnetic filtration (HEMF) is used successfully to process kaolin (1). This is the first successful commercial application of a new level of magnetic separation equipment and processing technology which resulted from the joining of four major concepts (2).

1. Discovery of the importance of retention time in mineral separation.
2. Development of very high gradient matrix collectors.
3. High intensity fields in wet magnetic separators (up to 20 kilogauss).
4. Modern design of large high field magnets.

Use of longer retention time permits finely divided particles to migrate and be captured by a magnetized collection surface. The canister in the magnet is filled with a matrix of steel wool, screens made of sharp thin ribbons, or other filamentary material which provides very high gradients. Modern electronic and magnet technology led to the design of a magnet with a high field throughout a large cavity. A diagrammatic sketch of a large high intensity magnet is shown on Figure 1. The diameter of the canister can be up to 84 inches with a height of 20 inches. Up to 100 tons of kaolin per hour can be processed through the 84 inch unit. Fabrication of equipment larger than 84 inches is feasible but the problems involved in shipping and for on site fabrication are such that it is probably more efficient to consider multiple installations of 84 inch machines.

High extraction magnetic filtration is very successful in removing iron and titanium impurities from kaolin. Potential applications for its use for beneficiation of other industrial minerals and coal have been demonstrated by Murray (3,4,5). Present HEMF equipment utilizes electromagnets to generate fields of 20 kilogauss. Power comsumption of this equipment is in the range of 400-500 KW.

The present HEMF equipment is optimized for separation of slurry containing fines below 200 mesh and preferably below 20 microns. Other matrix types can be substituted for stainless steel wool to accomodate coarser feed materials (up to 20 mesh) including Frantz screens, loosely packed coarse steel wool, steel shot, steel filings, and other filamentary material. New developments are underway in matrix design and composition which can greatly enhance HEMF technology.

MAGNETIC DESULFURIZATION OF COAL

The earliest work concerning the reduction of sulfur in coal by magnetic separation was described in a German Patent by Siddiqui in 1957 (6). Yurovsky and Remesnikov (7) published a paper in 1958 reporting that coal pulverized finer than 16 mesh size subjected to a thermal steam-air treatment reportedly made the pyrite more magnetic, which enhanced beneficiation when processed in a specially built magnetic separator. Sulfur reduction of 85, 74.9, and 70 percent were reported. Perry (8) reported that fine pyrite (65 to 100 mesh) treated in steam-air atmosphere at temperatures of 570^{o} to 750^{o}F for varying times, up to 10 minutes, resulted in increased quantity of pyrite becoming amenable to magnetic separation with increasing intensity of treatment. Kester (9, 10,) demonstrated that sulfur could be reduced to a greater extent by making a high intensity magnetic separation directly on raw untreated coal without employing the

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thermal pretreatment step. Thus, by pulverizing the coal to a typical power plant size and by magnetically separating the coarse 48 by 200 mesh size fraction significant sulfur reduction was achieved.

Kester reported that pyritic sulfur accounts for 40 percent to as much as 80 percent of the sulfur content of most coals (9). Gluskoter and Simon (11) reported that the mean total sulfur content in 474 analyses was 3.57 percent in coals from Illinois and the mean value of pyritic sulfur in these same coals was 2.06 percent. They found that there is on an average approximately one and one-half times as much pyritic sulfur in a sample as there is organic sulfur.

Macroscopic pyrite occurs in coal in, 1)veins, usually thick and filmlike along vertical joints, 2)lenses that are extremely variable in shape and size, 3)nodules or balls, 4)disseminated crystals and irregular aggregates. Microscopic pyrite occurs as small globules and blebs, fine veinlets, dendrites, small euhedral crystals, cell fillings, and replacement plant material.

Kester, Leonard, and Wilson (12) reported that the mass susceptibility of powdered pyrite was 4.53×10^{6} cgs units. Another value commonly used for the magnetic susceptibility of pyrite is 25×10^{-6} electromagnetic units per cubic centimeter. The strength of magnetism, which can be induced into a mineral is dependent upon the permeability of the mineral according to the equation.

$$B = uH$$

B - magnetic induction in gauss in the mineral
u - Permeability of the mineral
H - magnetic field intensity in gauss

Therefore the susceptibility is:

$$B/H = 1+4\pi K$$

K - magnetic susceptibility expressed in electromagnetic units cm/gm/sec

If the value of K is positive, the mineral is termed paramagnetic and experiences a force which tends to attract it in the direction of increasing magnetic gradient. If K is negative, the mineral is diamagnetic and experiences a repulsive force. Ferromagnetic minerals, such as iron, experience strong magnetic forces in the direction of increasing magnetic gradient and thus have very large positive values of K. Coal is diamagnetic (13) and pyrite is paramagnetic. Thus, if the coal is crushed and pulverized fine enough to liberate the pyrite a good magnetic separation is possible.

A recent study by Kindig and Turner (14) reported on a new process for removing pyritic sulfur and ash from coal. The pulverized coal is treated with iron carbonyl vapor which puts a thin skin of magnetic material on the pyrite and ash but does not affect the coal. Thus magnetic separators yield a non-magnetic coal low in sulfur and ash and a magnetic fraction high in sulfur and ash.

The coal samples utilized for this report were pulverized so that 90 percent passed through a 200 mesh sieve. The samples were slurried at 30 percent solids for the wet magnetic tests. Frantz screens made from thin sharp ribbons of 430 magnetic stainless steel were used as the matrix in the canister. For the wet magnetic tests retention times of 30, 60, and 120 seconds were used for one series and multiple passes with a retention time of 30 seconds each were used for a second series. For the dry tests the series were run using gravity feed with multiple passes.

The coals used for this report were commercially mined coals in the Illinois Basin. These are Coals V and VI from Illinois and Indiana. The Indiana samples were from Warrick County in southern Indiana and the Illinois samples were from

Wabash and Williamson Counties.

Table I shows the sulfur content of the various samples.

TABLE I - Sulfur Content (Percent)

Coal	Total Sulfur	Inorganic Sulfur	Organic Sulfur
Indiana V	4.63	2.44	2.19
Indiana VI	4.17	2.20	1.97
Illinois V	3.59	2.39	1.20
Illinois VI	1.98	1.02	0.96

Figures 2 and 3 indicate the sulfur reduction obtained with increasing retention time and up to three passes through the magnet using wet separation methods. Figure 4 shows the sulfur reduction obtained using a dry separation technique. The data shows that the best results as far as sulfur reduction is concerned was attained using a slurry and three passes through the magnet each with a retention time of 30 seconds. Table II is a summary of the sulfur reduction obtained using both wet and dry separation methods.

TABLE II - Sulfur Reduction (Percent)

Coal	Total S	Total S in Product	Inorganic S in Product	%Inorganic S in Product
Indiana V	4.63	3.00[1]	0.81	67
Indiana V	4.63	3.30[2]	1.11	55
Indiana V	4.63	3.78[3]	1.59	25
Indiana VI	4.17	2.30[1]	0.10	85
Indiana VI	4.17	2.45[2]	0.25	78
Indiana VI	4.17	3.31[3]	1.01	39
Illinois V	3.59	1.96[1]	0.83	65
Illinois V	3.59	2.18[2]	0.99	59
Illinois V	3.59	2.87[3]	1.67	30
Illinois VI	1.98	1.15[1]	0.21	79
Illinois VI	1.98	1.29[2]	0.32	69
Illinois VI	1.98	1.57[3]	0.61	40

1. Wet-three passes 2. 120 second retention 3. Dry-three passes

One sample of Coal V from Indiana was pulverized so that 90 percent of its particles passed 325 mesh and using 3 passes with 30 seconds retention each, 93 percent of the pyritic sulfur was removed. Further tests on fine grinding and optimization of the test conditions are now being carried out in the authors laboratories. In addition to the sulfur reduction, ash reduction is being measured. The loss of coal in the magnetic fractions varied from six to fourteen percent and is related to the size and distribution of the pyrite in the coal.

ECONOMICS

Quinlan and Venkatesan (15) recently discussed the economics of coal preparation coal cleaning processes comparing jig versus heavy media plant circuits. The operating cost of the jig plant was $0.85 per clean ton and for the heavy media circuit $1.25 per clean ton. The capacity of each was 500 TPH and the capital cost of the jig circuit was $6,000,000 and for the heavy media circuit $8,500,000.

To design a cleaning circuit to produce 500 TPH of coal would require five 84 inch magnets. The capital cost (installed) would be approximately $8,000,000.

	Cost per hour	Cost per ton 500 TPH
Amortization of installed separators over 10 years 80,000 hrs.	100.00	0.20
Magnet power (2000 KW @2¢ KWH)	40.00	0.08
Pumping and Flushing Power (1000 @2¢ KWH)	20.00	0.04
Labor	15.00	0.03
Maintenance	10.00	0.02
TOTAL	185.00	0.37

The cost per ton of magnetic cleaning is relatively low compared with the other two methods cited. In addition to the potential removal of 70 to 90 percent of the inorganic sulfur, the ash content of the coal would be substantially reduced. A high percentage of the following impurities, if present, in addition to pyrite, would be removed magnetically because all of these minerals and rocks have a mass susceptibility higher than pyrite except for limestone: siderite, limonite, ferrous and ferric sulfate, limestone, clay and shale, and sand.

Much additional research and development work must be done to substantiate the preliminary results reported in this paper. Several studies are underway in the author's laboratories at Indiana University. With the advent of coal becoming the major energy source in the United States in the foreseeable future, magnetic cleaning of coal looks as if it will be a viable method of processing which can provide a low sulfur, low ash coal.

CONCLUSIONS

1. High Energy Magnetic Filtration (HEMF) is proven commercial process.
2. Fine pulverization to liberate the pyrite is necessary before magnetic filtration.
3. Sixty-five to ninety percent of the inorganic sulfur can be removed from the coal by HEMF processing a coal slurry.
4. The estimated cost per ton is lower than using a jig circuit or heavy media circuit.
5. The coal product from the HEMF process will be relatively clean both from sulfur and ash content.

REFERENCES CITED

(1) Iannicelli, J. "High Extraction Magnetic Filtration of Kaolin Clay" Clays and Clay Minerals, Vol. 24, Pergamon Press (1976) pp 64-68

(2) Iannicelli, J. "Assessment of High Extraction Magnetic Filtration" Special Report-RANN-National Science Foundation (1974)

(3) Murray, H.H. "Beneficiation of Selected Industrial Minerals and Coal by High Intensity Magnetic Separation" IEEE Transactions of Magnetics, Vol. MAG-12 (1976) pp 498-502

(4) Murray, H.H. "High Intensity Magnetic Beneficiation of Industrial Minerals-A Survey" Preprint 76-H-93 Amer. Inst. Min. Engrs. (1976)

(5) Murray, H.H. "High Intensity Magnetic Cleaning of Bituminous Coal" Proc. National Coal Research Symposium - Louisville, Ky., Oct. (1976) pp 74-81

(6) Siddiqui, S. "Desulfurization and Concentration of Coal" German Patent 1,005,012 (1957)

(7) Yurovsky, A.Z. and Remesnikov, I.D. "Thermomagnetic Method of Concentrating and Desulfurizing Coal" Coke and Chemistry, Vol. 12 (1958) pp 8-13

(8) Perry, H. "Potential for Reduction of Sulfur in Coal by Other Than Conventional Cleaning Methods" Symposium-Economics of Air Pollution Control, AICHE 59th Nat. Meeting 1966

(9) Kester, W.M., Jr. "Magnetic Demineralization of Pulverized Coal" Mining Engring.,Vol. 17 (1965)

(10) Kester, W.M., Jr. "The Effect of High Intensity Magnetic Cleaning on Pulverized High Sulfur, Bituminous Coals" Thesis, School of Mines, West Virginia Univ. (1966)

(11) Gluskoter, H.J. and Simon, J.A. "Sulfur in Illinois Coals" Illinois State Geol. Survey, Circular 432 (1968) 28 p.

(12) Kester, W.M., Jr., Leonard, J.W., and Wilson, E.B. "Reduction of Sulfur from Steam Coal by Magnetic Methods" Tech. Report 31, Coal Research Bureau, West Virginia Univ. (1967)

(13) Wooster, W.A. and Wooster, N. "The Magnetic Properties of Coal" Bull. British Coal Utilization Research Assoc. (1944)

(14) Kindig, J.K. and Turner, R.L. "Dry Chemical Process to Magnetize Pyrite and Ash for Removal from Coal" AIME Preprint 76-F-306 (1976)

(15) Quinlan, R.M. and Venkatesan, S. "Economics of Coal Preparation" AIME preprint 76-F-108 (1976)

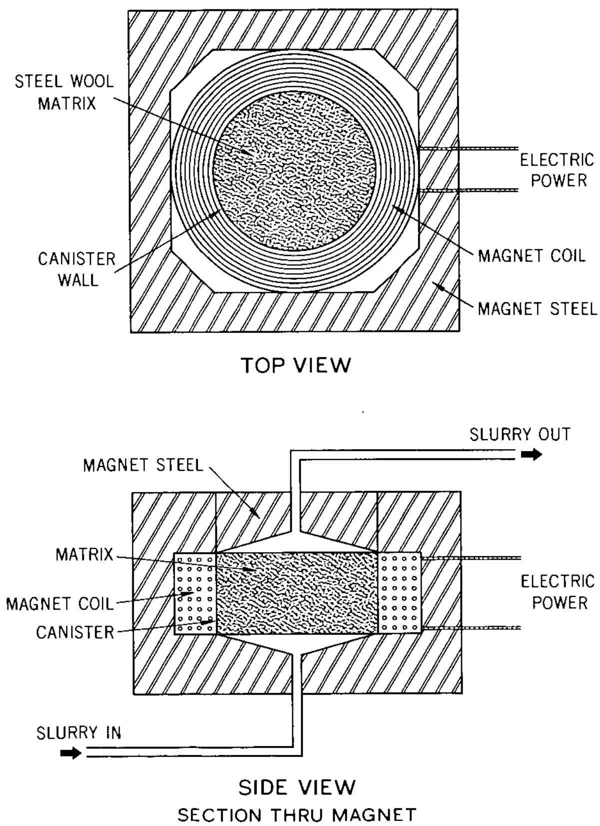

FIG. 1-Diagrammatic Side and Top View of HEMF Unit

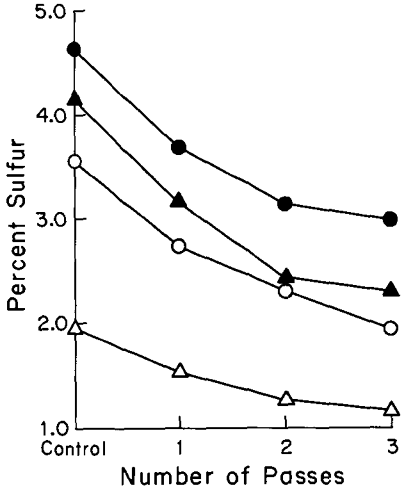

Fig. 2 Sulfur content after 1, 2 and 3 passes at 30 seconds retention each (wet).

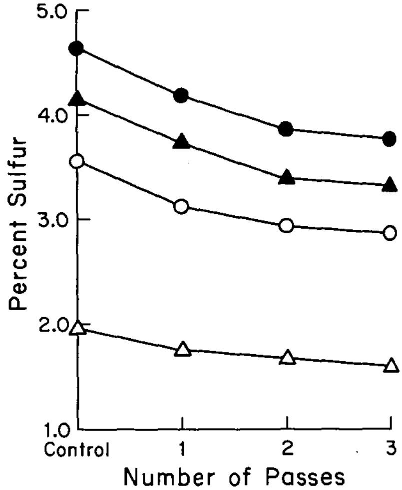

Fig. 4 Sulfur content after 1, 2 and 3 passes (dry).

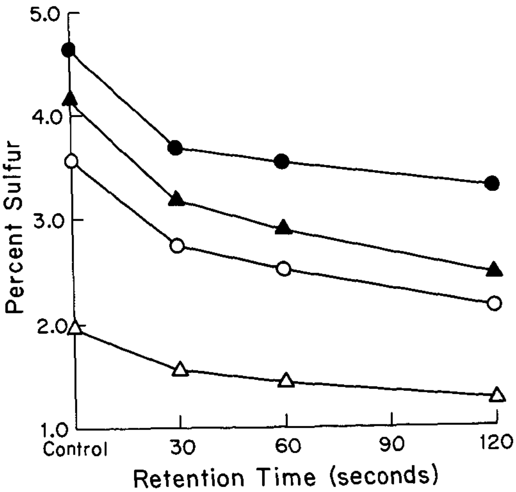

Fig. 3 Sulfur content with increasing retention time (wet).

EXPLANATION

● Coal V, Warrick Co., Ind.

▲ Coal VI, Warrick Co., Ind.

○ Coal V, Wabash Co., Ill.

△ Coal VI, Williamson Co., Ill.